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THREE DIMENSIONAL DEPTH ILLUSION DISPLAY

FIELD OF THE INVENTION

This invention relates to the field of optical display devices with three dimensional depth effects.

BACKGROUND OF THE INVENTION

If two planes are displaced by a small distance from each other, the front plane being transparent, each plane being printed with a two dimensional pattern, the front one of opaque strips, and the rear one with a complementary pattern which can include shapes of objects, or graphic designs, motion of one plane with respect to the other produces an appearance of motion in the resulting visual field. This relative motion can be produced either by physically moving one plane relative to the other, or by motion of the observer as he passes in front of the planes. The front plane acts as a moving shutter, exposing or concealing different parts of the rear plane as the position of the front plane changes relative to the line of sight from the viewer's eye to the rear plane. The result is a visual field which changes with the viewer's position, or with the relative position of the planes if their motion is used for the effect. These changes can be used to create an illusion of motion in the viewer's mind.

This moving shutter effect has been widely used for many decades for creating an illusion of motion or change in the appearance of two dimensional display devices, such as those used for street advertising signs, billboards, point-of-sale promotion, or in artistic display pieces, and much prior art is known. Such devices in various forms have been shown in U.S. Patents No. 829,492 (Spiegel), 911,561 (Spiegel), 2,374,371 (Morch), 3,484,969 (Newland), 3,918,185 (Hasala), 4,263,737 (Simon) and others.

More recently, similar devices have been proposed, but using the well known Moire effect to create the illusion of movement in the resulting patterns. In the Moire effect devices, both planes are printed with periodic patterns with a small spatial

frequency difference between the front and rear patterns. The combination of these two periodical patterns creates a third 'beat' pattern whose appearance depends on the difference in spatial frequency between the two patterns. For clarification, it should be pointed out that in the familiar demonstration of the Moire effect, it appears as though the effect is obtained using two line patterns at a slight angle, each with identical line frequency. Even in this case, there is nevertheless a frequency difference, generated by the fact that the two patterns are held at a slight angle, such that the frequency component of the one which overlaps with the second is the line frequency multiplied by the cosine of the angle between them.

As in the previous case, the Moire pattern is given the appearance of motion by varying the position of the front screening plane with respect to the line of sight between the observer and the other plane, either by moving one of the planes or by movement of the observer. Examples of such moving Moire pattern devices are shown in U.S. Patents No. 4,789,573 (Jenkinson), 4,975,620 (Tacquard et. al.), 4,300,068 (Baird et. al.), 3,643,361 (Eaves), 3,811,213 (Eaves), 3,827,797 (Eaves) and 4,586,798 (Eaves).

The principal physical difference between these two groups of devices is that in the first, non-Moire group, the screening plate acts as a moving shutter that exposes a different image according to the relative position between the planes, while in the Moire effect devices, it is the combination of two periodical patterns which creates a moving pattern when the relative position between the planes is changed. Furthermore, in the first group, any image can be used but only discontinuous changes produced, whereas in the second, Moire pattern group, the images are limited to those which consist of segmented combinations of periodic patterns. On the other hand, the Moire pattern motion can be made continuous.

Methods for creating depth illusion, without the need to use any special viewing aids such as spectacles, can also be divided into these two groups. The familiar lenslet array method, wherein different images are seen in different viewing directions, is similar to the moving shutter principle, except that for depth illusion, the different exposed images are simply views of a three dimensional object or scene from different directions. Use of the lenslet array effect imposes strict limitations on the ranges and angles from which the depth illusion can be perceived.

The second group, of continuously moving Moire patterns, can also be used to create an illusion of depth. In U.S. Patent No. 3,643,361, and as further developed in

U.S. Patent No. 3,811,213, Eaves uses this effect to create an illusion of depth in a display device. The main part of Eaves' patent deals with the creation of an illusion of motion, as previously described. In his embodiment, one constant frequency dot patterned transparency is moved in relation to another constant frequency dot patterned transparency to produce the motion illusion. Eaves also points out, however, that depth illusion is observed when the dot patterns of the two transparencies have a small frequency difference between them, and are spaced apart by some small distance.

He explains that the depth illusion is created by means of two effects. Firstly, the parallax effect, also known as retinal disparity, which arises from the slight difference between the view of the Moire pattern perceived by each of the viewer's eyes. The viewer's mental processes use this difference to visualize the depth, as in regular stereoscopic vision. This mechanism is further emphasized by means of the second effect, called motion parallax, whereby movements of the head cause the Moire pattern of the object to move in relation to its background. The viewer's mental perception of depth also makes use of this relative movement effect, and can thereby distinguish even fine depth differences. When both the dot frequencies and the transparency spacing are optimally chosen, a depth illusion is created. In the above mentioned patents, Eaves shows how a two dimensional object can be made to appear suspended in space or standing out in front of a more distant background plane. The two dimensional object appears to be in the real plane of the display apparatus and the background appears as a more distant plane. Eaves also pointed out, in col. 15, line 10 of U.S. Patent 3,811,213, that the closer the frequency of the two patterns, the greater the retinal disparity and motion parallax, and hence the greater the depth illusion.

However, when an attempt is made to create a full three dimensional visualization of an object or scene using Eaves' method to create an appearance of several levels of depth behind the real display plane, a serious perception problem arises. Even if the image is built up of only a few layers with different depths, the result is visually confusing, and it is difficult to perceive the correct depth order of the planes.

The problem exists because of a combination of effects arising from the nature of Moire patterns. As mentioned by Eaves, the closer the frequency of the two patterns, the greater the depth illusion. However, a basic property of all Moire patterns is that the closer the frequency of the two patterns, the wider the resulting stripes. This can be understood by considering the way in which the two varying periodic patterns interact

by analogy with wave theory. When two waves with close frequencies interfere, a third wave is created with a frequency equal to the difference in frequency between the two original waves. This third wave is known as a 'beat' wave. The closer the frequency of the two waves, the smaller the frequency of the 'beat' wave, or the Moire pattern in the analogy. Stated alternatively, the closer the frequency of the two patterns, the wider the period of the stripes of the observed Moire pattern. This explains the source of the effect which causes the above mentioned problem with Eaves' method.

The combination of these two effects implies that the further behind the real surface plane an object or a plane is made to appear, the larger the resulting period of the Moire pattern. However, this result is in direct contradiction to a third visual perception mechanism of depth in the human mind, which was not mentioned and probably not noticed by Eaves, related to the apparent size of distant objects. This mechanism is that if two views are compared, each with a periodical line pattern of different period, the one with the larger period appears to be closer. This effect arises from the tendency of the mind's visual perception to assume that all lines are equally spaced in reality, and that the observed differences in period are caused by differences in depth. This effect is routinely used in graphic arts to enhance the impression of visual depth in pictures of three dimensional objects.

Therefore, when Eaves' method is used to create three dimensional objects made up of several planes at different depths behind the real plane, these two depth perception mechanisms contradict each other in the observer's mind, and the result is confusing, unclear and unrealistic. Since Eaves, in the above mentioned patent, showed an embodiment with only one background plane at a one specific depth, this visual contradiction was not apparent and therefore not noticed.

Another problem with the prior art presented in the Eaves patents is that the use of dots for providing the motion effect in two orthogonal directions results in low contrast of the Moire pattern.

A further drawback of the prior art shown by Eaves is that it proposes the use of patterns made up of two dimensional regions of constant frequency. This only allows the formation of discrete planes in an image with different apparent depths, but it does not enable the formation of true three dimensional continuous images, such as spheres, cylinders or bottles.

To the best of applicant's knowledge, no prior art exists which suggests or shows how to create continuous three dimensional images, which images show correct perspective and mutual movement of their constituent parts as the observer moves in front of the images. The creation of such images, to show realistic articles such as spheres, bottles, cans, etc. would be of great importance in the field of large format advertising for such products, in the form of signs, billboards, point of purchase promotions, or in other fields where a spectacular, eye catching, three dimensional image is needed. Small format advertising and graphic effects, such as are used on credit cards, phone cards, mail advertising material and the like, would also benefit greatly from such an invention.

SUMMARY OF THE INVENTION

The present invention seeks to provide an apparatus and method for producing continuous three dimensional images possessing an illusion of depth by means of the Moire effect.

The Moire image produced by a preferred embodiment of the present invention is formed by overlaying, one on top of the other, two predetermined patterns of nearly vertical lines, at least one of whose line period or spatial frequency varies slowly. This combination of patterns creates a third image pattern whose appearance depends on the difference between the two patterns. Since the two planes in this apparatus are displaced from each other by a small distance, the overlap of the two substantially periodic patterns, and hence also the Moire image, depends on the position of the observer.

The depth illusion is created using the parallax effect, which arises from the difference between the picture that each of the eyes sees. This mechanism is reinforced by the effects of movements of the observer's head, an effect known as motion parallax. When the observer's head is moved, the observed Moire pattern moves relative to the real plane, so that it looks as though it is at a different depth. Therefore, the relation between the speed of movement of the observer's head and the speed of movement of the Moire pattern supports and strengthens the depth illusion created by the parallax effect, and thus helps the observer to distinguish even fine depth differences.

The contradiction mentioned above between the two competing depth perception mechanisms is solved in the present invention by creating the depth illusion using two

planes, at least one of which has a variable frequency pattern, instead of using planes with constant frequency patterns, as suggested by Eaves. By this means, both the Moire pattern period and the apparent depth can be controlled independently, so that the contradiction can be avoided.

The method mentioned in the Eaves patents for increasing the illusion of depth behind the real plane is to decrease the frequency difference between the two patterns. An alternative method, which is used in the present invention to avoid the visual perceptive contradiction which arises using Eaves' method, is by increasing the absolute frequency of both patterns, keeping the frequency difference constant. As a result, for the same speed of movement of the viewer's observation point, the Moire pattern seems to move more quickly than that with a lower frequency, since, for the same movement of the observer, a greater absolute number of periods of the front pattern move relative to the rear pattern. The Moire pattern thus appears more distant. In the same way, the difference in appearance of the image between the viewer's two eyes is also increased accordingly, so that the parallax effect is also increased.

These two ways of increasing the depth can be combined, making it possible to control both the Moire pattern period and the depth by varying both the average frequency and the frequency difference of the patterns. By using slowly varying periodic patterns in either one or both of the front and rear planes, instead of the constant frequency pattern suggested by the Eaves method, the resulting Moire pattern period or strip width can be controlled independently from the apparent depth or the relative speed of movement of the Moire pattern. Thus, the contradiction apparent in the prior art between the two depth perception mechanisms can be resolved. As a result, even continuous three dimensional surfaces and objects can be created.

Furthermore, the use of two slowly varying periodical patterns enables more flexibility in the creation of three dimensional objects such as spheres, boxes, cans, bottles or faces. Since the period and speed of movement of the Moire pattern can be controlled at every point of the display, the pattern can be changed continuously over the display so that it appears to flow over the required continuous three dimensional surface. The pattern period or width can be controlled to express not only the relative apparent size-depth perception mechanism, but also the simple geometric perspective effect, which causes features of a tilted surface viewed from the front to narrow with the cosine of the tilt angle. This effect further enhances the feeling of perspective and depth

generated in this object, and if, for instance, the object has a round shape, its image appears to rotate as the observer moves sideways. Other graphical depth enhancement features, such as shading or special lighting effects can also be added to the image.

The creation of three dimensional objects or surface illusions can also be achieved by varying the distance between the surfaces imprinted with the periodic patterns. Thus a Moire pattern with three dimensional depth illusion can be created even using two plates or surfaces with shapes of constant spatial frequency printed on them, provided that the distance of separation of the surfaces is varied according to the effect required. This embodiment of the present invention is, however, more dificult to manufacture than the embodiment described above using flat surfaces with patterns of varying period.

The use of almost vertical lines in a preferred embodiment of the present invention, rather than the two dimensional array of dots used in Eaves'invention, limits the motion and depth effects produced to the horizontal direction. Since the major parallax effects take place in a horizontal direction, because of the horizontal arrangement of the eyes, this limitation itself is not a serious drawback. The use of vertical lines does however enable another significant advantage, since the use of lines causes the image contrast to be increased many fold, thus making the device more useful commercially.

There is thus provided in accordance with a preferred embodiment of the present invention, at least two surfaces, one of which is a substantially transparent sheet displaying a predetermined nearly vertical periodic first line pattern, and the other of which displays a black and white or a colored periodic second line pattern, with a slightly different period from the first pattern. The period of either one or both of the line patterns has a slow variation in the horizontal direction. The patterns are separated by a small distance of at least several times the period of the line patterns, such that the combination of both patterns produces a Moire pattern which changes with the observer's position in front of the first surface, and creates an illusion of continuous depth in the image, without the need for any special viewing aids, such as special spectacles.

There is further provided in accordance with another preferred embodiment of the present invention, a device for displaying an image with an illusion of depth, including a first surface, the first surface being substantially transparent and at least part

of which displays a first pattern of features of periodic nature with a substantially constant period, and a second surface, at least part of which displays a second pattern of features of periodic nature with a substantially constant period, and wherein the first surface is intermediate an observer and the second surface, the period of the second pattern differs incrementally from the period of the first pattern, the period of at least part of at least one of the patterns has a slow variation, and the first and second surfaces are spaced apart by a distance larger than the period of either of the first and second patterns, and wherein the incremental difference in the periods of the patterns, the spacing between the first and second surfaces, and the variation in the period of the at least part of at least one of the patterns are selected such that the interaction of the first and second patterns produces a Moire image exhibiting continuous three-dimensional visual effects.

In accordance with yet another preferred embodiment of the present invention, there is provided a device for displaying an image with an illusion of depth as described above and wherein the lines are arranged in a substantially vertical direction and the variation of the period of at least part of at least one of the patterns takes place in a substantially horizontal direction.

In accordance with another preferred embodiment of the present invention, there is provided a device for displaying an image with an illusion of depth as described above and wherein sections of the features or lines are shifted horizontally with respect to each other in different horizontal bands of the patterns, to produce images with varying vertical detail.

In accordance with still further preferred embodiments of the present invention, there is provided a device for displaying an image with an illusion of depth as described above and which exhibits realistic three dimensional effects either by means of the static parallax effect resulting from the mutual diplacement of the views of the image as seen by each of an observer's two eyes, or by means of the motion parallax effect resulting from changes in the appearance of the image with change in the position of the viewer.

There is further provided in accordance with yet another preferred embodiment of the present invention, a device for displaying an image with an illusion of depth, as described above, and wherein the feature size of the image changes with the apparent depth in such a way as to comply either with the mind's perception that distant objects appear to have narrower details and close objects have wider details, or with the

geometric perspective effects that features on a tilted surface appear narrower than those on a flat surface by approximately the cosine of the tilt angle.

There is still further provided in accordance with another preferred embodiment of the present invention, a device for displaying an image with an illusion of depth, as described above, and wherein the brightness of features of the image changes with the apparent depth in such a way as to comply with the shading effect or any other desired lighting effect.

In accordance with yet another preferred embodiment of the present invention, there is provided a device for displaying an image with an illusion of depth as described above, and which can be viewed by the observer's naked eye without the need for any special viewing aids such as special spectacles.

In accordance with a further preferred embodiment of the present invention, there is provided a device for displaying an image with an illusion of depth as described above, and wherein the second surface is either transparent, translucent or opaque.

There is further provided in accordance with yet another preferred embodiment of the present invention, a device for displaying an image with an illusion of depth, as described above, and wherein the spacing of the surfaces is between 5 and 100 times the pattern period.

There is still further provided in accordance with another preferred embodiment of the present invention, a device for displaying an image with an illusion of depth, as described above, and wherein the surfaces are printed with patterns of the same or different color, or wherein the second surface background color is different from that of any of the other printed patterns.

In accordance with a further preferred embodiment of the present invention, there is provided a device for displaying an image with an illusion of depth as described above, and wherein either:

(a) the two surfaces are disposed on the opposite sides of a transparent plate, or

(b) the first surface is disposed on one side of a transparent plate, and the second surface is a thin printed layer disposed close to the second side of the plate, or

(c) both first and second surfaces are thin printed layers disposed on both sides of a plate, or

(d) the first surface is disposed on one side of a transparent plate, the second surface is disposed on one side of another plate, the plates being disposed at a fixed

distance from each other such that the surfaces are spaced from each other by a predetermined distance

In accordance with yet another preferred embodiment of the present invention, there is provided a device for displaying an image with an illusion of depth as described above, and wherein at least one of the first and second surfaces is constructed of wire netting, or is thin and flexible such that it can be rolled on a cylinder.

There is further provided in accordance with yet another preferred embodiment of the present invention, a device for displaying an image with an illusion of depth, as described above, and wherein the device is illuminated from the front, the rear or from at least one of its edges.

There is still further provided in accordance with yet another preferred embodiment of the present invention, a device for displaying an image with an illusion of depth, as described above, and which is constructed and operative for large area use such as in billboards, or for small area use such as in credit cards.

In accordance with yet another preferred embodiment of the present invention, there is provided a device for displaying an image with an illusion of depth including first and second surfaces, the first one of which is transparent, each having at least part of its surface printed with a predetermined pattern of substantially periodic features, the surfaces being spaced apart by a distance considerably larger than the period of the features, and the spacing of the surfaces being varied in a predetermined manner such that the interaction of the two patterns produces a Moire image exhibiting continuous three dimensional visual effects when viewed from the first surface side of the device.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description, taken in conjunction with the drawings, in which:

Fig. 1 shows a schematic drawing of the pattern with slowly horizontally varying frequency used on the front surface to produce the images shown in Figs. 3 and 4.

Fig. 2 shows a schematic drawing of the pattern with slowly horizontally varying frequency used on the rear surface to produce the images shown in Figs. 3 and 4.

Fig. 3 shows a schematic example of a Moire pattern having three dimensional visual effects, of half of a vertically striped sphere protruding from a background plane,

obtained using apparatus constructed and operated according to a preferred implementation of the present invention, and as viewed by an observer's left eye.

Fig. 4 shows a schematic example of a Moire pattern having three dimensional visual effects, of half of the vertically striped sphere protruding from a background plane, as shown in Fig. 3, but viewed from a horizontally slightly moved observation point, such as would be seen by the right eye.

Fig. 5 is a view of a flat checkered pattern to be produced by the Moire effect.

Fig. 6 shows the appearance of either the front or rear surface patterns required to produce the checkered Moire pattern shown in Fig. 5.

Fig. 7 illustrates schematically the different object patterns used for the contrast analysis of the resulting Moire pattern for the case with one or two colors.

Fig. 8 illustrates schematically the different object patterns used for the contrast analysis of the resulting Moire pattern for the case with two or three colors.

Fig. 9 is a schematic view of a device constructed and operated according to a preferred embodiment of the present invention, consisting of a single thin transparent plate with front and rear surfaces, each printed with their respective pattern with slowly horizontally varying frequency, and separated by a small predefined distance, being the thickness of the plate.

Fig. 10 is a view of a double layer device. One layer is a transparent plate with one side fully or partially printed with a pattern with slowly varying frequency. The other layer is made of a thin material which is not necessarily transparent, printed with the second pattern with slowly varying frequency.

Fig. 11 is a view of a triple layer device. The two thin layers are located close to the opposite sides of the thick transparent plate. The thin layer closer to the observer is transparent and fully or partially printed with a pattern with slowly varying frequency. The other layer is made of a thin material, not necessarily transparent, and is printed with the second pattern with slowly varying frequency.

Fig. 12 is a view of a double plate device, showing the two thick plates.

Fig. 13 is a view of a billboard type of display device, constructed and operated according to a preferred embodiment of the present invention, using a fixed net as the front surface medium.

Fig. 14 is a view of a billboard display device as described in Fig. 13, but using a rolling net or thin layer for the front surface medium.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Reference is now made to Fig.1 and Fig. 2 which show the patterns on the front and rear surfaces of a preferred embodiment of the present invention. These two surfaces are separated by a small distance. These two patterns are combined to produce a Moire pattern when observed from the front side. The front surface preferably comprises a subsstantially transparent sheet imprinted with vertical or nearly vertical line patterns with slowly varying period in the horizontal direction, as shown in Fig. 1. The rear surface is imprinted with a color or black and white horizontally slowly varying periodic pattern, such as in Fig. 2. The front surface must be substantially transparent to allow the light reflected from or transmitted through the rear surface to pass through the front surface and combine in the observer's eye with that from the rear surface. Unless the apparatus is back lit, the rear surface need not be transparent. The patterns printed on the two surfaces are constructed and operative in such a way that their combination produces the desired Moire pattern, with an illusion of depth in the observer's mind.

When used as the front and rear patterns respectively in an apparatus constructed and operated according to a preferred embodiment of the present invention, the patterns shown in Fig. 1 and Fig. 2 create a three dimensional visual image of half a vertically striped sphere protruding from a background plane.

Figs. 1 and 2 constitute a real working pair of patterns, which can be used to demonstrate the present invention, once a transparent copy of the front plane has been made. The plane spacing has to be approximately 5 cm. The features of the patterns in these two figures are much enlarged from those of a device which would give detailed images in a hand-held model of this size. For such a model, the real periods would be too small to be seen by the naked eye. The patterns in Fig. 1 and Fig. 2 are drawn to an exaggerated scale in order to clarify the principle through which the effect of the present invention is produced, and in order to show the detailed features of the patterns for the purpose of this description. This is the reason why, in order to view the resulting image using these two patterns, a plane separation of 5 cm has to be used, as compared with a spacing of the order of a 0.5 to 5mm for an image of this size to realistic scale. The level and scale of detail shown in Figs. 1 and 2 would be typical for a large area display sign, suitable for viewing at a distance of several meters or more.

Fig. 3 shows schematically the Moire pattern resulting from combination of Fig. 1 and Fig. 2, as seen from a single observation point representing the left eye of the observer. Fig. 4 shows schematically the Moire pattern as seen from an observation point moved slightly horizontally, representing the right eye of the observer. The combination of these two images in the observer's mind creates the three dimensional visual effect of half of a vertically striped sphere protruding from a background plane, with both the hemisphere and the background plane appearing to be behind the real display plane.

As is seen in Fig. 3, at the center of the sphere 31, the Moire pattern period, or in other words, the width of the Moire pattern strips, is larger than the width of the strips at the edges of the sphere 32 and 33, or in the background plane 34. Thus, according to the mind's size-perception mechanism, the center of the sphere looks closer to the observer. The width of the Moire pattern strips at each point of the sphere surface is determined by the frequency difference at the corresponding points of the two patterns with slowly varying frequency shown in Figs. 1 and 2. It is seen in Figs. 1 and 2 respectively, that the period of the two horizontally slowly varying periodic patterns at the centers 11, 21 of the sphere is larger than the period at the edges of the sphere 12, 13, 22, 23, or than the period of the background periodic function 14, 24. Consequently, the resulting Moire pattern at the center of the sphere 31 as seen in Fig. 3 by the left eye, is displaced by only 1/4 of a strip width from the position of the image of the center of the sphere 41 seen in Fig. 4 by the right eye, while the background pattern 34 seen by the left eye moves by a whole strip width compared to that of the right eye 44. The relative background movement of one complete strip can be clearly seen in Figs. 3 and 4 in the pattern stripes next to the left or right vertical borders. The quarter strip movement at the center of the sphere can also be discerned in Figs. 3 and 4, but with more difficulty. As a result of the above movements, the background plane 34 seems to the eyes to move more than the center of the sphere 31. This, according to the parallax mechanism, causes the background to appear located further behind the real picture plane than the center of the sphere.

Furthermore, the width of the Moire pattern strips at the center of the sphere 31 is larger than the width of the strips of the background 34, as previously explained. Thus, both according to the relative size depth perception mechanism, and according to the parallax mechanism, the sphere center looks closer to the observer. Consequently, in

accordance with this preferred embodiment of the present invention, not only do these two perception mechanisms not contradict each other, but they even reinforce each other to improve the depth illusion of the three dimensional continuous objects. The creation of clear, impressive, and in particular, unambiguous illusions of three dimensional continuous objects is the major advantage of the present invention.

The observed depth of each point of the display depends on the local periodicity of the front pattern, the local periodicity of the rear pattern, the distance between them and the observer location. By continuously changing the period of the front and rear patterns, it is possible to create continuous three dimensional images, such as the sphere shown in Fig. 3 and Fig. 4. In addition to the above mentioned effect, relating to the width of the Moire pattern strips, the front and rear patterns are constructed and operative such that the strips of the resultant Moire pattern image appear to cover the surface of the sphere with the correct perspective of a three dimensional image. Because they are viewed at a steep angle, the geometric perspective effect causes the strips at the sides of the sphere to appear narrower than their real width by the cosine of the angle between the viewing direction and the surface normal. As a result, when an observer moves horizontally, he sees a three dimensional sphere, whose strips "flow" over the sphere surface, continuously changing position, shape and width in such a way as to give the illusion that the sphere is rotating in his direction of movement, and show the correct perspective changes expected from a real life sphere. This effect enhances the three dimensional illusion and the visual impression of the display.

To illustrate the way in which a complex image including areas with discretely varying vertical detail, is constructed from the base front and rear surface patterns, the construction of a checkered pattern is now considered. Fig. 5 shows such a pattern. It is useful in understanding how such a pattern is constructed by considering it to be an ammendment to the stripes shown in the background in Fig. 3 and Fig. 4. Each vertical stripe is split up into alternating black 45 and white 46 sections, with adjacent stripe patterns out of phase with each other.

This effect is achieved by inverting the printed and non-printed areas in either the front or rear surface pattern, in horizontal strips whose height is equal to the height of the desired square height. Fig. 6 shows the pattern required on either the front or the rear surface in order to produce the checkered Moire pattern schematically shown in Fig. 5. The 180° phase changes between successive horizontal strips 47, 48, which produce

the contrast changes in the vertical direction are clearly visible. The width of the checkered squares is determined, as with the stripes in the background, by the period of the Moire pattern, which is determined by the frequency difference between the front and rear patterns. In general, Moire patterns with such discretely variable vertical detail are produced from front and back patterns with sections of their periodic features shifted horizontally with respect to each other in different horizontal bands.

Fig. 5 shows a checkered pattern at a fixed depth level. As with the striped sphere shown in Figs. 3 and 4, it is possible to add depth illusion to the checkered pattern by selecting the absolute frequency of the two patterns and the frequency difference, as in any Moire pattern created by the present invention. The size of the squares of the checkered pattern can be chosen to improve the depth illusion by using the relative size depth-perception mechanism, and thus by creating the illusion that the checkered pattern flows over a continuous three dimensional surface with movement of the observer's position, as before. Similar periodical patterns can be created by similar means.

It should be pointed out that the terms "horizontally slowly varying frequency pattern" or "horizontally almost periodic pattern" refer only to those parts of the patterns which make up continuous sections of objects to be Moire imaged in the device. At the edges of objects, such as at the boundary between the sphere and the background, large discrete changes of the pattern period may be used. The changes of the pattern in the vertical direction control the vertical dependence of the observed Moire pattern, as demonstrated in the checkered pattern example.

The desired period of the pattern with horizontally slowly varying frequency is sufficiently small that it is not discerned by the observer when the apparatus is viewed from the optimal distance. At this distance, only the Moire pattern of the combination of the two patterns is seen by the observer. Therefore, the changes in the Moire pattern required to produce the features of the image itself, both vertically and horizontally, are naturally on a much larger scale than the horizontal period of the pattern, as mentioned in the previous paragraph.

The required difference in period between the front and rear patterns of varying period is in the range of about ± 20%. In order to obtain good depth illusion, the period of the front and rear patterns should be in the range of about 5-100 times smaller than

the distance between the two planes. Patterns with larger ratios also give the desired effect, but are more difficult to produce.

In the present invention, the optimal range over which the depth effect is observed is large compared with other depth illusion displays, such as lenslet array displays, that can be viewed without any aids, such as special spectacles. Furthermore, in contrast to the lenslet array method, the observed depth in a Moire effect display looks almost the same from any distance of observation, because of the difference in the physical principle of the illusion. The upper limit of the observation distance is determined by the ability to physically discern the Moire pattern. This limit can be set at very large distances by making the period of the Moire patterns wide.

The depth effect also can be seen from a wide range of angles, at least ±45° from a vertical plane perpendicular to the display plane, although the viewed depth changes somewhat according to the cosine of the angle of the observer relative to the perpendicular to the display plane. These properties make the depth illusion method according to the present invention very suited for street advertising boards, since it can be clearly seen from a wide area. The present invention can be implemented in devices with a wide range of sizes. It can be used for small sized graphic effects on items such as credit cards, where it could replace the hologram as the security device, on postcards, small signs, point of purchase promotional signs, bus stations signs and right up to giant billboards.

In general the frequency of the pattern in the front plane, as shown in Fig. 1, is lower than the frequency of the corresponding area in the rear plane, as shown in Fig. 2. This causes the observed sphere and background to appear behind the real display plane, since with this order, the Moire pattern moves in the same direction as the observation point relative to the display. As shown in the Eaves patents, if the frequency of the pattern in the front plane, Fig. 1, is higher than the frequency of the rear plane Fig. 2, the resulting Moire pattern moves in the opposite direction to the movement of the observation point relative to the display. The Moire pattern therefore looks as though it is in front of the display apparatus. However, in this case, too, the use of the above described preferred embodiment of the present invention enables the width of the Moire pattern strips to be controlled separately from their apparent depth, by using two varying periodic patterns of appropriate form.

In the prior art invention of Eaves, the use of dots to produce the front and back patterns enables the Moire pattern to move in both horizontal and vertical directions. However, since the human eyes are separated horizontally, and it is the parallax effect which provides the major depth perception effects, it is possible to sacrifice the vertical motion of the Moire pattern, and as is shown hereinunder, significantly to increase the contrast of the Moire effect. This is done in a preferred embodiment of the present invention by using a pattern of nearly vertical lines instead of dots. The contrast of the resulting Moire pattern is consequently increased by up to six times, compared with the prior art dot patterns, and the overall depth clarity is significantly increased.

In the same way, it is possible to achieve the same increase in image contrast by use of a pattern of substantially horizontal lines, with the slowly varying change in pattern period taking place in a vertical direction. Such a preferred embodiment would be useful for small devices, where the major part of the depth illusion could be obtained by movements of the head up and down, rather than by static parallax effects.

Fig. 7 and Fig. 8 demonstrate differences between the dot pattern devices of the prior art, and the line patterns proposed by preferred embodiments of the present invention. Referring to Fig. 7, box 110 is a typical cut out section of the depth illusion apparatus where dots are used for the creation of the Moire effect, as per the prior art shown by Eaves. Plane 111 is the front plane, which is the one closer to the observer, and plane 112 is the rear plane. According to Eaves' prior art, both planes are transparent and printed with opaque dots of the same color. Fig. 7 shows schematically the four possible extreme cases of overlap 113 - 116 for the two planes 111 and 112 when viewed by the observer. Image 113 shows the observer's view when the device is viewed from a direction exactly perpendicular to the planes 111, 112, such that the dots of the two planes overlap exactly. Image 114 is an illustartion of the view seen when the observation point is moved slightly horizontally.

The image contrast change of the Moire image is defined as the percentage partial change in opacity of the total image as a fraction of the maximal possible change. A contrast factor of 1 would mean that the resulting Moire pattern changes from full transparency to full opacity. Thus for the difference between 113 and 114, the contrast change is 1/4, if we approximate the dots by squares of the same dimension, in order to simplify the calculations. This approximation is continued for the rest of the calculations, without losing the validity of the conclusion. If the dots were not

approximated by squares, the exact contrast change would have to be multiplied by $\pi/4$ to obtain an exact result.

View 115 shows the mode seen if the observation point is moved vertically from 113 by a small amount, or alternatively, if the pattern of the dots on one of the planes 111 or 112 is moved vertically by the same amount. View 116 is the result of a horizontal movement from the situation of view 115. This time the partial change of the opacity between the two possible horizontal modes is zero because the dots in 115 do not overlap as in 113, and the transmission is unchanged. To obtain the overall contrast change of this depth illusion device, the average of the two cases of 113-114 and 115-116 has to be taken, since they both have the same probability of occurring, since the vertical height of the observation point is unknown to the designer. The resulting contrast change is therefore the average of 1/4 and 0, namely 1/8.

The contrast improvement provided by the present invention can be divided into two steps. Firstly, changing the pattern on one of the planes from dots to vertical or near vertical lines, as shown in device 120, doubles the Moire effect contrast, which in itself significantly improves the depth clarity. Secondly, by using vertical or nearly vertical lines in the second plane too, as shown in device 130, the contrast is again doubled.

The box 120 shows a typical section of a depth illusion apparatus with one plane, in this case the front one 121, printed with a line pattern, and the other 122, with dots. Both planes are printed with the same color as before. 123-126 shows schematically the four extreme cases of overlap, analogous to modes 113-116 for the case with the dots only. The partial change of the printed area to the background area in going from 123 to 124 is 1/4 of the total area. In order to cover the case of an opaque or translucent rear plane, with its own specific background color, the definition of the contrast has been expanded to be the ratio of the partial change between the printed color and the background color as a fraction of the maximum possible change. A unity contrast change implies a Moire pattern change from full printed color to full background color. 125 and 126 show the other two possible modes that arise when the observation point is moved slightly vertically. The difference between 125 and 126 is again a horizontal movement of the viewing point. This time the partial change is the same as the change between 123 to 124, so the average contrast between transparency and opacity or between the background color to the printed color of the resulting Moire

pattern is (1/4+1/4)/2=1/4. As previously mentioned, this result is alone double the contrast obtained using two planes with dots.

The second improvement is shown in device 130. Here both of the planes, 131 and 132, are printed with a vertical or nearly vertical horizontal line pattern. As in the previous cases, the front plane must be transparent but the rear plane does not have to be so, and both of the planes are printed with the same color. For this case, vertical movement of the observation point does not change the observed pattern at all. There are thus only two modes of overlap of the two planes 131 and 132, as shown in views 133 and 134. The partial change of the printed area to the background area is 1/2 of the total maximal possible change, so the contrast change is 1/2. This result is double the contrast change obtained in case 120, and four times that of case 110.

The use of colors for the Moire pattern is another improvement of the present invention. It is possible to obtain at least the same contrast improvement over the case of the dots when three different colors are used in the different planes. Fig. 8 shows the same contrast analysis as Fig. 7, but using different colors for the two planes. The three cases are for both planes with dots 210, one plane with dots and one with stripes 220, and both planes with stripes 230. For this calculation, it is assumed that the front plane 211, 221 or 231 is transparent and printed with a black pattern. The rear plane 212, 222 or 232 is transparent or translucent or opaque with one background color and a pattern of dots or lines of a different color. With observer movement, the Moire pattern switches color between the two rear plane colors and for this case, the contrast change is defined as the partial change between the two colors of the Moire pattern from the maximum possible change. Thus, since the Moire pattern consists of two different colors, the black areas from the front plane dots should not be counted in the contrast definition.

Returning to Fig. 8, for the case of two planes both printed with dots case 210, views 213-216 shows schematically the four possible modes of overlap of the two planes 211 and 212. 213 and 214 show the images of 210 seen from two horizontally displaced observation points. The partial change of the color of the combination of the two planes is 1/4 of the total area if the dots are approximated by squares of the same dimension. The total colored area, excluding the area of the black dots, is in this case 3/4 of the total area. Thus, according to the three color definition of the contrast change, it is (1/4) / (3/4), which equals 1/3. 215 and 216 shows the other two possible views of

210 seen from two horizontally displaced observation points vertically displaced from those of views 213 and 214. This time the partial change of the color between the two possible horizontal modes is zero because the dots in 215 do not overlap. The overall contrast change of the two dots planes case is obtained by averaging the two cases of 213-214 and 215-216 as before, giving a contrast change of (1/3+0)/2=1/6.

In the second case the front plane is changed from dots to vertical lines or nearly vertical lines, as shown in 220. The same colors and contrast are used as in the previous case. 223-226 shows schematically the four possible modes of overlapping for the two planes 221 and 222. 223 and 224 shows the two horizontal modes seen when the observation point is moved horizontal. The partial change of the background color to the printed color of the combination of the two planes is 1/4 of the total area. The total colored area in this case is 1/2 of the total area, so that according to the three color definition of the contrast change, it is (1/4) / (1/2) = 1/2. 225 and 226 show the other two possible horizontally displaced images seen from an observation point moved a little vertically. This time the partial change is the same as the change between 223 to 224, so the average contrast between the printed color to the background color of the resulting Moire pattern is (1/2+1/2)/2=1/2. This result is three times the contrast change obtained in the two dot planes case shown in 210.

The third case is shown in 230. Here both of the planes, 231 and 232, are printed with a vertical or nearly vertical line pattern, with the same colors as in cases 210 and 220. This time vertical movement of the observation point doesn't change the observed pattern at all. Thus only two modes of overlap, 233 and 234 need be considered. The partial change of the printed color to the background color of the combination of the two planes is 1/2 of the total area. The total colored area in this case is 1/2 of the total area, as in 220. Thus, according to the three color definition of the contrast change, it is given by (1/2)/(1/2)=1. So the contrast change between the colors of the Moire pattern resulting from a horizontal movement is 1. This result is six times better than that obtained with two dot planes, as shown in case 210.

If we use the same contrast change definition as that previously used for cases 110, 120 and 130, which compares the partial change of color to the total area, the improvement obtained by using vertical line or nearly vertical line patterns rather than a dot pattern is still a factor of four. The second definition of the contrast, as used in cases 210, 220 and 230, is more suited to the case of two rear plane colors and a black front

pattern. If the front plane pattern is not black, but printed with a third color, the analysis shown here can be extended using the same principles by anyone skilled in the art, and shows that the fourfold improvement in contrast still exists.

The above embodiments of the present invention all use vertical lines in order to take advantage of the increased contrast and visibility afforded by this configuration. It should be noted though, that when contrast is not of primary importance, but the presence of some three dimensional visual effects also in the vertical direction is of importance, further embodiments of the present invention can be proposed using dots instead of lines. In such an embodiment, the dots must be arranged in arrays with spatial frequencies which are slowly varying in both directions according to a predetermined pattern, in order to obtain realistic, non-confusing depth effects, as per the method proposed in this invention.

Fig. 9 to Fig. 14 show examples of devices useful for implementing the present invention. Fig. 9, shows the simplest embodiment, using a single transparent plate 50, printed on both sides. The plate can be made of any transparent material such as glass, PVC, polycarbonate, etc. The side closer to the observer, called the front side 51, is partly or wholly printed with a semitransparent pattern of horizontally slowly varying frequency vertical or near vertical lines. Semi-transparent in this context is used to mean that the area between the opaque lines is transparent while the line itself is as opaque as possible. This pattern can fully or partially fill the front side of the plate. It can consist of one color or more, and some of the area can be fully opaque or transparent.

The other side of the plate, the rear side 52, is printed with another horizontal pattern of vertical or near vertical lines with slowly varying frequency, which, like the first side, fully or partially fills the plate area. This pattern does not have be semitransparent, although it can have transparent or opaque areas too. However, there should be a significant visual difference in color, brightness or transparency, between the printed horizontally almost periodic pattern and the background of this pattern, in order to obtain a Moire pattern with good contrast. This printed horizontally almost periodic pattern can be of one color or more. It should be understood that, as stated previously, Fig. 9 can also be implemented with the spatial frequency of the pattern on only one of the two sides of the plate being slowly varying. This applies also to the other embodiments shown in the following Figs. 10 to 14.

The plate thickness can be in the range from 0.5mm to 10cm, or even thicker if required. One possible implementation is a POP sign or bus station poster, which require a plate area of 1 to 2m^2. Using conventional printing methods, such as screen printing, the pattern period can be as small as 0.25 mm or even smaller, and with a plate thickness of 2mm, a good sense of depth illusion can be achieved. Such a plate can fit into existing poster fittings without any changes. Such posters are usually back lit, which is also good lighting for the depth illusion device.

Fig. 10 shows a second possible embodiment of the present invention using a transparent plate 53 printed on one side and a thin printed layer 54 attached or otherwise positioned close to the other side. The plate can be made of any transparent material. The side closer to the observer, the front side 55, is printed with a semitransparent pattern of horizontally almost periodic, nearly vertical lines, as before, fully or partially filling the front side of the plate. As before it can consist of one color or more, and some of the area can be fully opaque or transparent. The thin layer 54, on which is printed the second horizontally almost periodic pattern of vertical or near vertical lines, fully or partially filling the image area, is juxtapositioned or attached to the other side of the plate, the rear side. The thin layer can be transparent, and made of a material such as PVC or any other transparent polymer, or can be an opaque material such as paper, which is easier to print by, for example, offset, laser or ink jet printing. The thin layer can also be translucent to increase the brightness and the visibility of the image. The use of the thin layers simplifies the printing process, in that instead of printing both patterns on the plate, only one pattern need be printed on the plate. The pattern can be of one color or more, as before.

The preferred embodiment shown in Fig. 11 further simplifies the printing process. Here both patterns are printed on a thin layer. The two thin layers are attached or otherwise located close to both sides of a plate 56. The thin layer 57 on the side closer to the observer, the front side, is transparent. It is printed with a semitransparent pattern of horizontally almost periodic nearly vertical lines, as before, fully or partially filling the front side of the plate. As before it can consist of one color or more and some of its area too can be fully opaque or transparent. The other thin layer 58, which is printed with the second horizontally almost periodic pattern fully or partially filling the image area, is attached to the other side of the plate, the rear side. This thin layer can be transparent, opaque or translucent, as before.

Fig. 12 shows a preferred embodiment of the present invention comprising two plates. The plate closer to the observer, the front plate 59, is transparent and can be made of any transparent material as before. This plate is printed with a semitransparent pattern of horizontally almost periodic, nearly vertical lines, as before, fully or partially filling the front side of the plate. As before, it can consist of one color or more and it can have some of the area fully opaque or transparent as well. As in the embodiment shown in Fig.10, this pattern too can be printed on a thin transparent layer attached to the front plate to simplify the printing process. The second plate, the rear plate 60, is printed with the second horizontally almost periodic pattern of near vertical lines, fully or partially filling the image area. This plate can be transparent or translucent if it is back-lit, or opaque if it is front-lit. As for the front plate, a thin layer printed with the second pattern can be attached to the rear plate instead of printing directly on it, to simplify the printing process. The rear thin layer can be transparent, opaque or translucent to gain image visibility and sharpness. The two plates are disposed in a fixed position relative to each other. The advantage of this device is that it can be used for large signs, where a large separation between the two patterns is required. Separating the thick plate into two separate plates makes the construction lighter and cheaper.

Figs. 13 and 14 shows two additional embodiments of the present invention especially suitable for use in large size billboards. All the implementations previously shown in Figs. 9 to 12 can be used to create the depth illusion effect for billboards. However because of the large area of these signs, the use of a net with orthogonal wires provides a cheaper and simpler method. The vertical strips of the net are used to create the Moire effect, while the horizontal strips are used solely for supporting the vertical strips.

Fig. 13 shows an embodiment where the front net 70 is held in a rigid frame 71. Fig. 14 shows an embodiment where the net 75, in this illustration the front net, is rolled onto a rotating cylinder 76. The advantage of the rolled net is the ease with which the net can be mounted or removed when changing signs, or when changing the billboard from regular use to use with the depth illusion effect, and back. Instead of using a net for the front plane, a thin flexible transparent foil printed with a horizontally almost periodic nearly vertical line pattern can be used to increase the range of possible three dimensional images.

The net has additional advantages because of the strength of the wires and their better resistance to strong winds. The rear plane 77 can be the regular billboard plate, which can be opaque and front lit, or translucent and back lit. The rear pattern is printed by one of the usual methods used for billboards, and is attached to the billboard plane. Illumination of the billboard can be done by using conventional methods, such as back lighting, or by using strong halogen projectors 78 located above or below the billboard on the inner side of the front plane, i.e. the side closer to the rear plane, as seen in the cut-away section of Fig. 13. This arrangement avoids casting a shadow of the front net on the rear plane, which would cause an additional unwanted Moire pattern.

It will be appreciated by persons skilled in the art that the present invention is not limited by what has been particularly shown and described hereinabove. Rather the scope of the present invention includes both combinations and subcombinations of various features described hereinabove as well as variations and modifications thereto which would occur to a person of skill in the art upon reading the above description and which are not in the prior art.